DOCUMENT RESUME

ED 290 637 SE 048 868

AUTHOR Arzi, Hanna J.; And Others
TITLE Teachers' Knowledge of Science: An Account of a Longitudinal Study in Progress.
PUB DATE Apr 87
NOTE 31p.; Paper presented at the Annual Meeting of the American Educational Research Association (Washington, DC, April 20-24, 1987).
PUB TYPE Reports - Research/Technical (143) -- Speeches/Conference Papers (150)

EDRS PRICE MF01/PC02 Plus Postage.
DESCRIPTORS Biology; Chemistry; College Science; *Foreign Countries; Higher Education; Misconceptions; Physics; Science Curriculum; Science Education; *Science Teachers; *Scientific Concepts; *Scientific Literacy; Secondary Education; *Secondary School Science; *Teacher Education
IDENTIFIERS Australia; Science Education Research

ABSTRACT

This paper describes the rationale for, methodology of, and some early results from a longitudinal study on science teachers' knowledge of science. Each of the participants is a university science graduate with a post-graduate university training for secondary school science teaching. The study focuses on two issues: (1) variations that occur in teachers' knowledge along their professional life, from the stage of being candidates in preservice training programs onwards; and (2) variations that occur among meanings teachers have for science concepts which are usually included in the school curriculum, due to their different disciplinary backgrounds (i.e., different training in biology, chemistry or physics). (Author/TW)

TEACHERS' KNOWLEDGE OF SCIENCE:

AN ACCOUNT OF A LONGITUDINAL STUDY IN PROGRESS

Hanna J. Arzi, Richard T. White, and Peter J. Fensham

Monash University

Melbourne, Australia

Abstract

The paper describes the rationale for, methodology of, and some early results from a longitudinal study on science teachers' knowledge of science. Each of the participants is a university science graduate with a post-graduate university training for secondary school science teaching. The study focusses on two issues: (a) variations that occur in teachers' knowledge along their professional life, from the stage of being candidates in preservice training programs onwards; and (b) variations that occur among meanings teachers have for science concepts which are usually included in the school curriculum, due to their different disciplinary backgrounds (i.e., different training in biology, chemistry or physics).

Teachers' Knowledge of Science:

An Account of a Longitudinal Study in Progress

Hanna J. Arzi, Richard T. White, and Peter J. Fensham

Monash University

Melbourne, Australia*

Paper presented at the annual meeting of the

American Educational Research Association

Washington, DC, April 1987

*Postal address:
Faculty of Education, Monash University, Clayton, Victoria 3168, Australia

A series of articles published twenty years ago in the Journal of Research in Science Teaching reflected on the science teachers needed for the 1980s (Bruce, 1966; Jacobson, 1967; Rutledge, 1967). Each article mentioned "appropriate preparation in science" as a preferred attribute for all 1980 science teachers - from primary through secondary school. The appropriate preparation is still an issue as we approach the end of the 1980s, yet related research has been scarce. Consequently, the existing research-based knowledge of, and insights from, the science knowledge of science teachers, is limited. A recent contribution toward filling in the gap has been made through a study with biology teachers conducted by Shulman and his group at Stanford University (Baxter, Richert, & Saylor, 1985; Friedler, Rosemond, & Schneider, 1986; Shulman, 1985).

In this paper we describe the rationale for, methodology of, and some early results from an ongoing longitudinal study on science teachers' knowledge across science disciplines and across time.

Rationale

The "appropriateness" of teachers' preparation in science has been frequently equated with the number of tertiary-level science courses they took. Recent meta-analysis, however, showed that this number has not been an impressive predictor of student outcomes in science (Druva & Anderson, 1983). This finding is not surprising when one considers the complex nature of the teaching process and its interaction with learning. Even if one decides - for the sake of research - to ignore this complexity and to focus solely on teacher knowledge in science, it would not be very useful to rely on the number sum of university courses, grade point average, or any other measure which defines teacher knowledge as a static entity created within the boundaries of tertiary institutions.

The label "teacher knowledge of science" used in this paper includes understanding, and hence stands for more than simple recall of factual information. It encompasses both substantive and syntactic knowledge (Schwab, 1964) as well as related pedagogical knowledge (Shulman, 1986). We suspect that tertiary education does not contribute equally to all these aspects of teacher knowledge. Furthermore, teacher knowledge is not shaped exclusively by tertiary institutions. According to the constructivist perspective of learning, science teachers' knowledge of science is a cumulative product of each one's preschool ideas, formal science education from pre-primary through tertiary institutions, non-formal science-related experiences, and ongoing science teaching experiences along the professional life. Hence, university studies account for only a part of a teacher's knowledge. The relative contributions of different sources of teacher knowledge may change over time due to the dynamic nature of each one's cognitive structure, where interactions are thought to occur between precedent and subsequent learning and unused knowledge becomes gradually less available.

How is the science knowledge of teachers shaped over time, beyond the boundaries of the prerequisite courses for certification? Understanding of how <u>teachers learn</u> science is needed for better understanding of how and what <u>teachers teach</u>, which in turn may contribute to the understanding of how <u>students learn</u>. This has been the assumption underlying our decision to embark on a longitudinal study on knowledge of science teachers from the formal completion of the university science degree through their teaching career. This is, therefore, a study of learning in science where the learners are science teachers and the context of their learning is their teaching and teaching-related experiences.

A major issue addressed in the present study is derived from the mismatch between the specialized and compartmentalized nature of university science courses, on the one hand, and the broad and integrated knowledge needed for teaching toward the generally accepted goals of school science, on the other hand. Recent literature in science education refers to discrepancies between "children's science" and "school science," where the latter is thought to be in accord with current scientists' knowledge (e.g., Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985). "Scientists' science," however, is not uniform, but fragmented into disciplines. Consequently, the same concept label (e.g., "Energy") or proposition (e.g., "Food contains energy") may have different connotations and interpretations in different science areas (e.g., physical vs biological sciences, or physics vs chemistry). This reflects different structures of knowledge and epistemologies. The concern, from an educational perspective, is that even if a student encounters only science teachers who have accurately retained all their university subject matter, the student may not be exposed to consistent presentations of concepts. Exposing students to different teachers with different understandings of a given concept, without clear attempts to differentiate among the related contexts and then reconcile the meanings and integrate the knowledge, can confuse the students and interfere with their conceptual learning and development. Teachers' abilities to avoid such confusion depend on the extent to which they are aware of possible variations in meanings across science disciplines. Subject-matter knowledge is not sufficient here - it has to be intertwined with pedagogical knowledge.

One would expect that different sorts of knowledge may interact, and integration of knowledge across science disciplines may be achieved, in parallel with the accumulation of teaching experience. There is some evidence, however, that this may not always be the case (unpublished results from Arzi's follow-up of a study by Arzi, Ben-Zvi, & Ganiel, 1984). Conditions that facilitate or that hinder growth of teacher integrated knowledge across disciplines should be elucidated.

In view of the rationale above, the present longitudinal study on science teachers' knowledge of science focusses on two issues: (a) variations that occur in teachers' knowledge along their professional life, from the stage of being candidates in preservice training programs onwards; and (b) variations that occur among meanings teachers have for science concepts which are usually included in the school curriculum due to their different disciplinary backgrounds (i.e., different training in biology, chemistry or physics). As part of the study of these issues, links between teacher knowledge and student learning are also explored.

The study started in 1985. Analysis of existing data is in progress, and collection of new data continues. In the present paper we describe the research context, design and methods, and share our tentative interpretations and some findings that have emerged from first analysis of data.

Methodology

Research Context and Design

Teachers' knowledge is being explored by longitudinal case studies of science teachers in urban and rural secondary schools in the Australian state of Victoria. We chose deliberately to study only teachers with full formal qualifications. The science preparation that preceded each participant's certification comprised (a) secondary school courses with final governmental examinations in at least two science subjects;

(b) university courses leading to a BSc with different combinations of majors and minors in science and mathematics; and (c) a full-year post-graduate university training for secondary science teachers, including two teaching methods courses - one in a specific science discipline and the other usually in general science or mathematics - leading to a Diploma in Education (Dip.Ed.). The teachers earned their BSc and Dip.Ed. in Victoria's biggest tertiary institutions: most of them at Monash University and some at the University of Melbourne.

The participants in the study were selected on the basis of each one's background information included in the form of application for enrolment in the Dip.Ed. course. The selection was guided primarily by our attempt to study teachers with various academic backgrounds across the different branches of the physical and the biological sciences. We also wished to start the follow-up with young teachers who proceeded more or less continuously from school through undergraduate studies to preservice training. Thus they were unlikey to be substantially different from each other in regard to their work experiences. This resulted in an entry sample of 33 student teachers. The 28 (15 females, 13 males) who participated throughout the study so far, are the focus of our discussion in this paper.

In view of the certification requirements for a degree with no less than second year tertiary level courses plus a teaching methods course in a given area, the distribution of science teaching certifications in our sample is as follows: nine biology teachers, 13 chemistry teachers (including three who are also categorized as biology teachers) and 10 physics teachers (including one who is also a chemistry teacher). Half of the teachers are qualified to teach mathematics as well. The science backgrounds of all the teachers comply with the requirements for general science teaching, yet less than one-third took a full general science methods course in their Dip.Ed. year.

The formal preparation of the teachers participating in the study is described in Table 1. The variety of backgrounds reflects our purposive sampling. The variety can be exemplified further if biology is broken down into areas: botany, zoology, physiology, microbiology, genetics or immunology. Although our sample was not intended to be representative of any larger teacher population, we believe that some of its features are (e.g., the limited physics background of fully certified biology teachers, and vice versa).

The total sample consists of two cohorts of teachers who have been followed from their preservice training onward, one year apart. The teachers in the first cohort (n=12) completed their Dip.Ed. in 1985, those in the second (n=16) in 1986. They will be referred to as the 1985 and the 1986 cohorts, respectively. The study of similar consecutive cohorts allows for a modified replication of the study with the first cohort, for purposes of confirmation or disconfirmation of findings via more or different kinds of data. This is particularly desirable when issues that were not initially attended to emerge through the study and seem to warrant further exploration.

The time line of the longitudinal follow-up is illustrated in Figure 1. The study of the 1985 cohort started toward the end of the Dip.Ed. course.* These teachers were followed up through their first year of actual teaching (1986) and the follow-up into their second year of teaching has begun. The study of the 1986 cohort started at the first week of the Dip.Ed. course.

---

*The academic year in Australia coincides with the calendar year: from late February through October. School starts early in February and ends prior to Christmas.

The combination of the currently available data from the two cohorts enables us to draw tentative conclusions on the development of teacher knowledge two years beyond the completion of the science degree. As the follow-up progresses, conclusions will be based on a "true" rather than on a "patched-up" longitudinal research design (Campbell & Stanley, 1963). In principle, the follow-up should stretch throughout the entire professional life of the teachers. In practice, however, the time line of the study will depend on the rate of attrition of the entry sample of teachers and on available research funds.

Types of Data and Data Collection

Data on teacher knowledge and related issues were obtained via sequences of intensive individual interviews, classroom observations, and analysis of teaching materials prepared by the teachers - mainly tests they had used to assess the knowledge of their students. Interviews were chosen as the principal research instrument since they enabled us to probe knowledge in flexible ways, according to each interviewee's experience. Furthermore, we believed that this personal mode of investigation could be conducted in a relatively non-threatening way, as opposed to the alternative of formal tests. Our wish to refrain from causing teacher research-related stress has been primarily due to moral-ethical reasons. We also hoped that this would help to build trust in the research intentions, and thus might influence teachers to continue their collaboration with us in the long term.

We note that the student teachers who were selected to participate in the study had no obligation to do so, yet they probably felt uneasy about refusing a request of academic staff members. This, however, was no longer the case when they became qualified teachers. Hence, the need to secure the long-term collaboration of teachers has been a major concern in the present study, and has affected its design and the sorts of data collected. For example, we decided to limit the frequency of repeated data collections, and to avoid overexposure of teacher knowledge deficiencies or misconceptions that may be interesting for the research purposes, yet also embarassing for the research subjects. These methodological compromises might not have been necessary had we begun the study with volunteers who received payment for their participation. On the other hand, a sample of volunteers would have introduced some biases.

Two series of individual interviews with each cohort, one to three hours per a single interview, all with the same interviewer, have been carried out so far. The 1986 cohort was interviewed upon entry to the Dip.Ed. course and at its end. The 1985 cohort was interviewed at the end of Dip.Ed. and a year later during visits to each teacher's school. What is referred to as "an interview at school" usually consisted of several sessions during a two-day school visit. These included audiotaped sessions during free periods, lunch breaks or after school, and informal conversations during breaks, teachers' yard duties, or en route to or from classroom observations.

The Interviews

The interviews were designed to elicit knowledge of a range of science concepts as well as to provide related contextual data. Some of the concepts were chosen prior to the interviews and were built into a similar interview script, while other concepts varied from one teacher to another. The choice of the latter concepts was determined by the content taught during classroom observations, and by the range of topics that emerged in responses to questions on other teaching experiences. Since the curriculum in Victoria is school based, the range of topics encountered in the study has been wide.

The Common Concepts Base-line. The concepts that were chosen beforehand to be dealt with across interviewees are energy (with special attention to the proposition "Food contains energy"), atom(s), cell(s), and pollution. Our reasons for choosing these concepts stem from their centrality in science education, and the range of their discipline affiliations. Energy is a major concept in both the physical and the biological sciences. Atoms (and other concepts related to the structure of matter) are likely to be formally taught within the context of physical science, yet they are mentioned in relation to biological science topics as well. Cells (in the biological sense, not electrochemical or solar cells) are unlikely to be mentioned beyond the boundaries of the biological sciences, and the way in which they are treated varies within these boundaries (e.g., zoology vs molecular biology). Pollution is an interdisciplinary concept with both science and non-science aspects. Unlike energy, atoms and cells, which are traditionally included in both junior and senior high school courses, pollution is not always part of the science curriculum.

We believed that the study of teachers' knowledge of the chosen concepts might expose the differential effects of teachers' disciplinary preparation, on the one hand, and their accumulating teaching experiences, on the other hand. Our special attention to the proposition "Food contains energy" was meant to provide us with data on the integration of knowledge across science disciplines. The reference to pollution aimed at exploring how teachers acquire knowledge from current everyday non-academic sources and mold it into their school teaching.

The interview series at the beginning of the preservice training (86#1 in Table 2) and one of the two series at its end (85#1 in Table 2) comprised five similar sets of questions, each related to one of the following five labels: ENERGY, FOOD AND ENERGY, ATOM, CELL, POLLUTION. The interviewer's in ictory comments referred to research objectives and hence to our wish t ork with teachers having a variety of science backgrounds, and to our awareness that some science topics dealt with in the interviews will be in and some out of each participant's expertise.

The first question in each set was (with slight modifications): "Can you spell out what comes to your mind when you think of [label]?" The question set on food and energy was preceded by a reference to a yogurt container bearing the information: "Per 100g: Energy 410kJ (98 Cal)," and explored knowledge related to the proposition "Food contains energy." If the response consisted of discrete words, the interviewer asked to phrase full sentences. The interviewer moved on to the next question when - despite encouragements to try to proceed which were followed by long wait-time - the interviewee persisted in signalling bodily or verbally "That's it ..." "I can't think of anything else, really ..." "I'm nearly scratching the bottom of the pit now ..." At this point the interviewee was shown the notes taken by the interviewer:

> These words were part of what you have just spelled out - some things I managed to pick up as you were talking. Do any of these words remind you of anything else you know about [label]? Of what?

Additional knowledge items were elicited via questions on what "all students ought to know" about each concept.

The above data were complemented by the interviewees' responses as to where they had gained their knowledge and how they rated it. The interviewees provided this data on each science item in the lists summarizing their knowledge utterances in response to previous questions. These lists were prepared by the interviewer, directly on questionnaire forms, as the interviewees were spelling out parts of their knowledge.

Each one was then presented with the lists and asked to think aloud while checking in the categories of knowledge sources (school, university, elsewhere) and self-ratings (I have little understanding; I understand but cannot spell it out; I understand and can tell something about it; I understand and can explain it well). Separate lists of science items and related self-ratings were produced for energy, food and energy, atom, cell, and pollution.

The raw data resulting from the first interview with each cohort consisted of audiotapes and five sheets of "concept profiles" for each participant. These materials provided the base-line for the longitudinal follow-up.

The Follow-up. The concept profiles were used for follow-up in the subsequent interview in the next year (Table 2). The interviewees were presented with each one's original concept profiles and asked to evaluate the contribution made by their last year's experiences (Dip.Ed. or teaching, for the 1986 and 1985 cohorts, respectively) and to reconsider their previous self-ratings in view of their current knowledge. As part of the follow-up of the first interviews, questions on the proposition "Food contains energy" were repeated with all the participants. Parts of the other question sets were repeated in a few cases.

In addition to the direct follow-up of the first interviews, the second interviews were designed to explore new aspects of subject matter knowledge. Thus, more than half of the interview at the end of the first year of teaching (85#2 in Table 2) dealt with actual school experiences. This usually started with questions on the lessons observed by the interviewer, and then went on to discuss related matters. These included provisions made at school for science teaching, the science syllabi, and the extent to which the teacher adhered or wished to have adhered to them, teaching difficulties, and self-evaluation of the adequacy of the preparation for science teaching, in view of the first year's experiences. Although many questions on these issues were not explicitly subject-matter related, the underlying orientation was. The interview was guided by a prepared script with a flexible sequence of core questions and alternative extensions. Since, as planned, the classroom observations usually served as starting points for questions, and since, as expected, the interview sessions emerged from preceding informal conversations, the actual course of an interview varied from one teacher to the other.

In all the interviews, the interviewer tried to secure the interviewee's trust by sharing the goals of the study and acknowledging the interviewee's contribution towards attaining these goals, as well as by expressing awareness of teacher difficulties - particularly those encountered by first-year teachers.

The interviews with teachers were conducted at each one's school. The school setting, and particularly the classroom observations, enabled us to observe the teachers in the professional ecosystem in which they grow. Our search for contextual data related to the teacher knowledge issues which are the focus of the present study, has been a major reason for classroom observations. The observations, nonetheless, have also been valuable sources of substantial data on teacher knowledge. So far we have observed 37 periods taught by the 1985 cohort toward the end of the first year of teaching (1-8 periods per teacher).

Some Findings

This paper is on a longitudinal study in progress. Our aim in presenting it at this stage is to discuss our rationale for embarking on a study on science teachers' knowledge of science and the methodology we have been using, rather than to dwell just on findings.

Erickson (1986) points to the "problem of premature typification" in qualitative/interpretive studies, that is, the researchers' tendency to leap to conclusions inductively early in the research process. We believe that the risks of premature leaps to conclusions are particularly big in longitudinal studies where the long wait-time between the research questions and the research answers can be sometimes frustrating. Consequently, researchers can be tempted to extrapolate emerging trends over time beyond the boundaries of the supporting empirical evidence. We will try to resist this temptation, since as this paper is being written tape-recorded data are still being transcribed, previously transcribed data are still being analyzed, and we have not yet collected data that will add a third point in time for each cohort (Table 2). The new data will extend beyond the first year of teaching which, like a first year in any career, may be quite different from the years that follow. Hence, the new data will assist in checking on the extent to which findings at the first year may be thought of as heralds of trends in the development of teacher subject-matter knowledge. That is, conclusions on the major issues we set out to study have to be delayed at least until the 1987 data are collected, transcribed and analyzed, in conjunction with reanalysis and reinterpretation of earlier data.

The next sections in this paper will complement the previous discussion of the rationale and methodology of the study, with some of the early findings that illustrate types of data we have been collecting, and suggest the thrust of our interpretations so far. We will use some aspects of the study with a member of the 1985 cohort, Moira, in particular her development of the concept of energy, as our starting point.

Moira's Development of her Energy Concept

> Well, energy I knew nothing about before much and I still know nothing about it much .... Energy - no, I don't feel like I know any more. My knowledge on energy I feel is very dicey, I don't feel confident in this at all to teach it. (1985, M502/85#1/p.17)*

This is how Moira described her knowledge of energy and the little effect her preservice training had on it, just before she completed her Dip.Ed. course. Twelve months later we observed Moira - now a school teacher - as she was teaching an energy unit within a grade 10 general science course. These were some of her comments at the end of her first year of full-time teaching:

> Yes, I'd say [that my knowledge of] energy probably has changed. Because I've taught, or I'm in the process of teaching the unit, I've been forced to read more about it and forced to try to explain it. So -- it would have changed, I'd say. Umm, I can't really say in what way .... I was pretty vague on energy .... Beforehand I could have given you calculations with potential and kinetic energy and that sort of thing. Now I think I've -- worked it out better in my own mind. (1986, M502/85#2/pp.38-39)

This verbal global description of change in knowledge was corroborated by Moira's self-ratings on her energy concept profile. Prior to teaching, she rated two-thirds of her knowledge items in the category "I understand but cannot spell it out," with one item in the lowest category "I have little understanding," and none in the highest category. After a year, two-thirds of the items were in the category "I understand and can tell something about it," none any more at the lowest category, but still none was referred to as "I understand and can explain it well."

---

*This and other quotes from interviews have not been edited. The notation for a pause is --, comments are given in brackets. The parentheses at the end enclose reference to the interview: year of interview, teacher code/interview code/page in the interview transcript. The interview code is the same as in Table 2.

Teaching = Learning. During school and university Moira coped with energy as far as the demands of her course work were concerned. Teaching experiences as a private tutor led to dissatisfaction with her knowledge:

> It's just not a concept I'm very clear on myself. I've just had to tutor a girl on it this week [laugh] and it wasn't very successful at all, because she kept saying "Well, is it something or is it just something somebody had made it up?" [laugh] .... Hopefully my concept knowledge on energy will change quite soon, actually, because I've got to retutor this girl next week [laugh]. I said I will have to look into that, because I really wasn't explaining very well at all ... She could do the problems ... all her questions were to do with the concept. She's saying, umm, that one question was: "Well, how does the electric current carry energy?" [Role playing, whispering to herself what went through her mind at the time:] How am I going to know? [Loud voice again:] "It just does it!" [short laugh] Sort of - I had no way of pulling that, you know, sort of, you know, how does electric current carry energy ... A lot of questions like that which I was - just was getting really stuck on.
>
> (1985, M502/85#1/p.7 & pp.18-19)

Moira's tutoring experiences triggered a change in her concept of energy, and her experiences as a school teacher promoted it. Thus, Moira's teaching experiences were, for her, also learning experiences. A major aspect of her learning was the identification of knowledge inadequacies, as illustrated by Moira's story of a laboratory discussion on the energy transformations involved with a light bulb connected to a battery:

> What energy transformations are going? It was a battery and a globe. OK, they got from the chemical potential to the electrical. I said "What other ones?" and they said "Light, heat" ... I told them "You can't create or destroy energy ... Disconnect the battery, it's there still as chemical potential." And this kid said "What if we leave it all on and the battery goes flat?" And I said "Well, it's all been used up as ... light and heat." And he said - umm - "But the light's gone out, so there's no more light energy." And I said "Oh well, the heat energy." "But it's all gone away, where does it go?" And I was thinking "Oh dear, I'm getting - " You know, really, I was getting to the point - I just didn't know what was going on then.
>
> (1986, M502/85#2/pp.9-10)

This story was used by Moira to illustrate a case in which textbooks couldn't be of much help. Obviously, this was an important incident in Moira's teaching and learning experiences, since she returned to it later, in response to another question:

> And he kept wanting to know: "But where does it go then? And then where does it go? And then where does it go? And then what happens to it, isn't it destroyed?" And I was thinking "Oh no, I can't explain this," and I said "No it isn't, it just sort of - go - you know, sort of - " I thought "Oh, that's not going to convince him of it," because a few of those kids were not convinced that you couldn't destroy energy, because the battery went flat and there was no more light ... And I realized my explanation did nothing to - umm - change that view ... I didn't explain that well at all, because I think I didn't fully understand it myself --
>
> (1986, M502/85#2/pp.30-31)

Moira added that the bothering questions were at the back of her mind when she was watching with her students a video on energy transformations, and this helped her to gain better understanding of that subject. The interview suggests that despite the improvement in her knowledge, the questions are still at the back of her mind.

We note that the students' questions with which Moira had been struggling are not trivial. For example, to deal with energy "lost" as heat one has to differentiate between available and unavailable energy, and hence to refer somehow to notions of random molecular motion and entropy. These are abstract ideas which are difficult to undersand and difficult to communicate in a simplified, yet undistorted way. They are taught in university courses largely in formal mathematical ways, in isolation from concrete energy-related phenomena, and as such they cannot well be presented in a school science classroom.

Knowledge Development as an Integration Process. Moira's difficulties in coming to grips with the concept of energy cannot be attributed simplistically to the lack of a sufficient number of science courses. She studied chemistry and physics through Grade 12, and her BSc studies included first year physics and second year mathematics and biology, in conjunction with a major in chemistry. As Moira pointed out, there is a mismatch between university studies and the goals of school science education:

> I studied very definite things which - whereas science teaching isn't teaching specifics. It's teaching a general thing. I only know specific things, whereas I don't know much about the general case of it.
>
> (1986, M502/85#2/p.23)

The interview question to which Moira was responding referred generally to the adequacy of her science preparation, but the response is particularly relevant to the case of energy. Undoubtedly, energy had been mentioned in more than one of the biology, chemistry and physics courses taken by Moira at university, though in isolation, unlike how she was later expected to teach at school. Some people are more successful than others in making links between seemingly discrete entities of knowledge. Apparently, Moira had not been very successful. Her teaching helped her realize that her knowledge base at the end of university was largely compartmentalized.

The lack of sufficiently integrated knowledge across disciplines came through in Moira's energy concept profile. In response to the question "What comes to mind as you think of energy?" she spelled out two blocks of items. The first block consisted of items related to energy in the everyday sense: personal energy and doing exercise, energy crisis and fuel. The items in the second block were related to energy as it is traditionally presented in physics: potential energy, kinetic energy, conversion of electric energy to heat, sound and light. Despite being a chemist by training, her list did not include any of the major energy-related chemistry concepts, such as bond energies, exothermic and endothermic reactions or electrochemical cells. The total absence of chemistry-affiliated items was not typical of the energy concept profiles of the other chemistry teachers.

Similarly, the profiles of biology teachers were found to be rich in biology-affiliated energy items (e.g., energy in photosynthesis or ATP). However, the physics affiliation that dominated Moira's energy concept profile was found to be the most frequent item affiliation across all teachers. Since the profiles were constructed during the preservice training, one may conclude that the prospective teachers tended to view energy as a "physics concept." This probably stemmed from the fact that although energy is <u>mentioned</u> in all the science disciplines, it is traditionally <u>taught</u> in physics, frequently in a separate chapter, involved with mathematical formulae and a host of drill and practice exercises.

The lack of integrated knowledge on energy can be further exemplified by data obtained through the question set on the proposition "Food contains energy." Moira, like other teachers, was surprised when the interviewer moved to this topic: "I don't sort of think of the idea of energy in food." (1985, M502/85#1/p.4) Her self-ratings of related knowledge items were very low (mostly "I have little understanding") and hardly changed through the first year of teaching. Moira attributed the lack of change to the fact that the topic was not part of her preservice course and field work, neither was it part of what she taught at school. Her teaching of energy followed largely materials found in an energy file of a colleague. The file did not include anything on food and energy, and Moira did not meditate on the possibility of teaching this as well.

In spite of Moira's evaluation of "no change," we detected a significant difference between the knowledge items she had spelled out before and after her first year of teaching. This was her first explicit reference to energy conversions in relation to food:

> And then there's conversion of them. I think that [food] is another thing that energy gets converted. But that's more in the energy area than food and energy, I suppose .... Yeah - umm - yeah, well, food is - it's stored as one type, it gets converted -- to another type -- so. energy conversions. (1986, M502/85#2/pp.42-43)

Here Moira integrated food with her new understanding of energy conversions of which she had spoken earlier in the interview. Moira's body language and mode of uttering the words quoted above, gave the impression that this integration was happening as she was talking about it.

Functionally Available Knowledge for Teaching. The immediately previous quote was taken from Moira's responses to "What all students ought to know about food in relation to energy?" This question and the one that followed were part of our attempts to learn more about Moira's knowledge:

> Interviewer:
> Can you point to some knowledge that you possess in regard to food and energy, yet you don't think that students ought to know it?
> Moira:
> I don't know very much about food and energy at all .... Most of my knowledge would be what I've just said, I think. I know very little about it.
> (1986, M502/85#2/p.43)

In this answer, as throughout the interview, Moira was honest and unpretentious. We believe, however, that she actually possesses more knowledge than she spelled out in response to our questions on food and energy. For example, she searched but failed to retrieve specific biochemical reactions, yet ignored the basic knowledge possessed by any chemistry graduate as to how bond breaking and bond formation in a chemical reaction may result in the net release of energy. This knowledge is directly connected with energy and food, but it seems that it was non-existent under the labels "food" or "energy" in Moira's cognitive structure. Almost none of the teachers mentioned clearly the connection between bond rearrangement in chemical reactions and the production of energy from food.

Our data suggest that Moira's and other teachers' schemata labelled "Food and energy" contain a lot of home-economics and weight-watchers-type knowledge, such as balanced diets or low-energy foods, but not enough "real science," which is probably stored elsewhere.* Teachers' pedagogical knowledge may rest in another niche altogether. In order to increase the functionally available knowledge for teaching food and energy, the available knowledge has to be integrated.

The point we wish to make is that school and university studies may provide teachers with all the knowledge items they need to teach a given subject. The knowledge, however, may not be sufficiently integrated (across science disciplines and beyond, including pedagogy). It may, therefore, not be functionally available knowledge for teaching. Knowledge growth in such cases would be a process of integration, rather than accretion of knowledge.

Supporting Growth. Students' subject-matter-related questions were an important factor in the growth of Moira's concept of energy. Such questions, however, are not a common factor across classes, as another teacher, Martin, comments:

> Generally, that sort of thing [students' questions] tend only to happen in senior classes ... and I think that's because it's probably the only place where I encourage that sort of - umm - freer discussion.
> (1986, M505/85#2/p.34)

Martin's reluctance to encourage questions in his junior general science classes is due largely to discipline problems. Laura avoids discussions for similar reasons:

> The only way to deal with them is to have them writing for most of the day .... I would rather we had a class discussion, but as you saw it works well for the first few minutes, and then they start getting restless and it's not worth it. (1986, L506/85#2/pp.14-15)

---

*The study on teachers' knowledge on the proposition "Food contains energy" was complemented with a study on the knowledge of their students on the same topic. The symptoms of insufficient integration of knowledge were prominent in the students.

Both Martin and Laura may be gaining classroom quiet at the expense of more meaningful learning for the class as well as for themselves.

Students' questions supported Moira in identifying problematic areas in her knowledge. Questions on factual information are usually easy to handle via reference books, sometimes even student textbooks may suffice. As Moira pointed out, this was not sufficient in the case of her students' questions. She struggled with them via reflection. Her reflections needed a sounding board, but this was missing. The staffroom in Moira's school is intimate and friendly, but very little substantial support was offered by the senior science staff:

> The staff sometimes forget that you're new ... they forget what it's like to be a new teacher, and you're having difficulties they don't have.
>
> (1986, M502/85#2/p.47)

The difficulties she and other teachers were referring to were primarily in relation to administration, discipline, and search for curricular materials. The support we are concerned with, in view of our data, is for growth of understanding and integration of knowledge. To exemplify this, we will return again to Moira's concept of energy.

When asked about the development in her energy concept, she pointed to the fact that now, unlike beforehand, "I can give scientific definitions, you know, the ability to do work." (1986, M502/85#2/p.39) This is the standard definition of energy in many textbooks, and as such, appeared in some of the energy concept profiles of our teacher sample. Physics educators, however, find it unsatisfactory and misleading. Since Moira does not feel that she has a problem with this definition, she is unlikely to reflect on it in particular. Even if the senior physics teacher at school is aware of the controversy involved with this definition, we suspect that he will not initiate a conversation with Moira on that matter.

Unlike Moira and other teachers who are largely left on their own, with more freedom than they would have liked to have, Glenn has support from a friendly and diligent senior science teacher. He visits with Glenn daily to ask what happened in yesterday's last period, to suggest how to arrange the materials in the next laboratory activity, or to offer a handout or a test. Glenn seems to be glad to be spoon fed, yet emphasized in the interview that he scrutinizes each handout and test before using it. One of the tests he adopted dealt with the balancing of ionic equations. Although his mentor is an experienced chemistry teacher and Glenn is a physics teacher who feels at ease with ionic equations (he said so in the interview), chemistry educators would question the appropriateness of the test assignments which included random combinations of existing ions to form non-existing compounds. What exactly bothers chemists probably does not concern every reader of this paper. The point is that a supportive environment does not necessarily facilitate growth.

Our data suggest that teacher subject-matter and related knowledge does not grow linearly with time just because a teacher gains experience. Reflection on experience is needed, <u>in conjunction</u> with an interactive subject-matter-oriented sounding board. Neither Moira, nor the other first year teachers we studied, had all the support they needed for growth. The single most important educational implication of this observation is the need for subject-matter-oriented inservice training. To a certain extent, we felt that the school visits and the interviews provided teachers in our research sample with a sounding board. Yet, since this was not designed to be an intervention study, we could not serve as an <u>interactive</u> sounding board. This was frustrating. A related frustration stems from the longitudinal nature of the study, which prevents us from sharing research findings with the teachers.

An End Without Final Conclusions

This paper reported on a longitudinal study in progress, hence overarching conclusions are out of place. Tentative interpretations have been interwoven within the presentation of some data. The findings that have emerged in the analysis of data on first year science teachers enable us to predict how their knowledge will develop in subsequent years. However, we choose not to set out any predictions now, because it will not be long before the next round of school visits and interviews is completed, and the information we obtain should contribute to more and better insights.

References

Arzi, H.J., Ben-Zvi, R., & Ganiel, U. (1984). Can teachers speak for their students? A comparison between teachers' and students' evaluation of a school science course. European Journal of Science Education, 6(4), 379-386.

Baxter, J., Richert, A., & Saylor, C. (1985, April). Science Group: Content and process of biology. Paper presented at the annual meeting of the American Educational Research Association, Chicago.

Bruce, M.H., Jr. (1966). Preparing the junior high school teacher, Model 1980. Journal of Research in Science Teaching, 4(1), 59-62.

Campbell, D.T., & Stanley, J.C. (1963). Experimental and quasi-experimental designs for research on teaching. In N.L. Gage (Ed.), Handbook of research on teaching (pp.171-246). Chicago: Rand McNally.

Driver, R., Guesne, E., & Tiberghien, A. (Eds.). (1985). Children's ideas in science. Milton Keynes, UK: Open University Press.

Druva, C.A., & Anderson, R.D. (1983). Science teacher characteristics by teacher behavior and by student outcome: A meta-analysis of research. Journal of Research in Science Teaching, 20(5), 467-479.

Erickson, F. (1986). Qualitative methods in research on teaching. In M.C. Wittrock (Ed.), Handbook of research on teaching (3rd ed., pp.119-161). New York: Macmillan.

Friedler, Y., Rosemond, S.S., & Schneider, S. (1986, April). Evolution of learning to teach biology: Teacher knowledge of subject matter in the classroom. Paper presented at the annual meeting of the American Educational Research Association, San Francisco.

Jacobson, W.J. (1967). Teacher education and elementary school science - 1980. Journal of Research in Science Teaching, 5(1), 73-80.

Osborne, R., & Freyberg, P. (Eds.). (1985). Learning in science: The implications of children's science. Auckland, New Zealand: Heinemann.

Rutledge, J.A. (1967). Preparing secondary school teachers for 1980. Journal of Research in Science Teaching, 5(1), 3-10.

Schwab, J.J. (1964). Structure of the disciplines: Meanings and significances. In G.W. Ford & L. Pugno (Eds.), The structure of knowledge and the curriculum (pp.6-30). Chicago: Rand McNally.

Shulman, L.S. (1985, April). The study of knowledge in teaching. Paper presented at the annual meeting of the American Educational Research Association, Chicago.

Shulman, L.S. (1986). Paradigms and research programs in the study of teaching. In M.C. Wittrock (Ed.), Handbook of research on teaching (3rd ed., pp.3-36), New York: Macmillan.

Table 1

Science course profiles of teachers in the study sample: Number of certified biology, chemistry and physics teachers taking courses in different science disciplines at the Grade 12 level or above (Grade 12 and/or 1st year university courses, vs 2nd year courses or above)

Teachers' discipline of certification	Discipline and highest level of study					
	Biology		Chemistry		Physics	
	Grade 12/ 1st year	≥2nd year	Grade 12/ 1st year	≥2nd year	Grade 12/ 1st year	≥2nd year
Biology (n= 9)	0	9	5	4	4	0
Chemistry (n=13)	2	7	0	13	9	1
Physics (n=10)	1	0	8	2	0	10
All (n=28)	3	13	13	15	11	10

Note. There is an overlap of three between the biology and the chemistry teachers, and one between chemistry and physics teachers.

Table 2

Main content features of the interviews

Time	Interviewees and interview content			
	1986 cohort		1985 cohort	
	Code	Content	Code	Content
Pre-preservice: Beginning of the Dip.Ed. course	86#1	Elicitation of items of knowledge, their sources and self-ratings, on energy, atoms, cells and pollution.		
Post-preservice: End of the Dip.Ed. course	86#2	A Subject-matter-related aspects of Dip.Ed. experiences. B Follow-up of 86#1: Updating the sources and self-ratings of knowledge on all topics + partial replication of knowledge elicitation.	85#1	Similar to 86#1
Teaching - 1: Last term of first year teaching	86#3	Script in preparation	85#2	A Subject-matter-related aspects of school experiences, including adherence to syllabi and teaching difficulties. B Follow-up of 85#1, similarly to 86#2.B.
Teaching - 2: Last term of second year teaching			85#3	Script in preparation

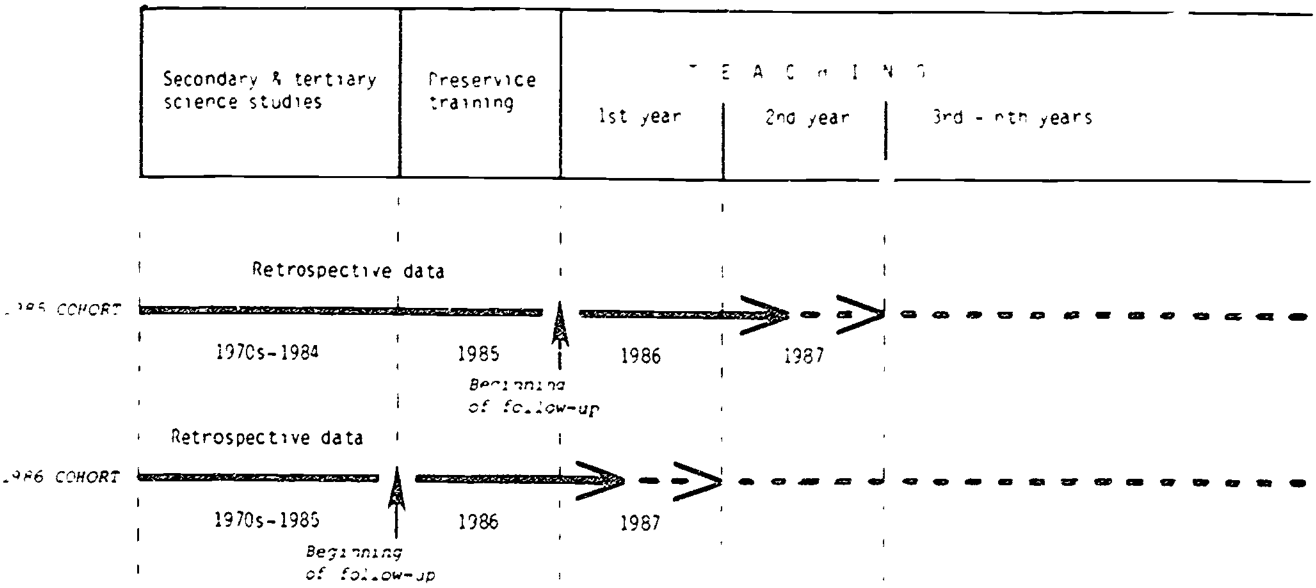

Figure 1

Time-line of the follow-up along phases of teacher development